Dental Caries in Nineteenth Century Upper Canada

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KEY WORDS caries; 19th century; Canada; diet

ABSTRACT This study examines the presence of dental caries in a large sample of adult skeletons from the 19th century cemetery of St. Thomas' Anglican Church in Belleville, Ontario. The cemetery was used from 1821 to 1874. Caries prevalence and frequencies of diseased and missing teeth were calculated both by observing summary statistics of individual rates and by the total sample of teeth. Postmortem tooth loss is low in this sample and antemortem tooth loss is highest in first mandibular molars, all other molars and then premolars. Age at death, but not sex, was found to be significantly related to the overall Caries Rate while both age and sex were significantly associated with the Diseased-Missing Index. The increase in diseased and missing teeth in older individuals is expected while the sex difference is not explained by simple dietary factors. When compared to reports on British and American samples, caries and antemortem tooth loss in the St. Thomas' sample is most similar to a pre-1850 British group and higher than American samples. Although there is undoubtedly a complex of factors contributing to caries prevalence in this sample, more data are required from large historic samples, particularly from the American northeast and late 19th century Britain, to have a clearer understanding of the influence of diet, cultural, and environmental factors affecting caries rates in historic populations. Am J Phys Anthropol 104:71–87, 1997.

The anthropological literature contains many reports of oral health and disease in past populations, particularly the prevalence of dental caries as a reflection of dietary changes. The reasons for this are clear, since as densely calcified tissue, teeth are well preserved and available for observation in most archaeological circumstances. In addition, the observation and identification of carious lesions are relatively simple to distinguish from other causes of tooth destruction.

Historical skeletal samples provide researchers with valuable information because the prevalence of dental pathology can be compared to complementary, documentary data about oral health, dietary composition, and dental hygiene. Much of the existing literature in this area deals with 18th and 19th century samples from Britain (Colyer, 1922; Brothwell, 1959; Hardwick, 1960; Rushton, 1965; Wells, 1968; Moore and Corbett, 1975; Corbett and Moore, 1976; Whittaker, 1993; O'Sullivan et al., 1993) and the United States (Angel, 1976; Angel et al., 1987; Owsley et al., 1987; Rathbun, 1987; Lanphear, 1988; Sciulli and Gramly, 1989; Sledzik and Moore-Jansen, 1991; Sutter, 1995). Comparative samples from similar

Contract grant sponsor: Canada Social Sciences and Humanities Research Council; Contract grant number: 410-91-1408.

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Received 8 February 1996; accepted 8 July 1997.

times in Upper Canada should prove interesting since they are affected by the political, economic, and close family ties to Britain as well as the geographic placement in North America and social and economic influences from the United States.

A survey of the British studies indicates a notable and consistent secular trend for increasing caries from Saxon times to the 20th century, including increases in total frequencies and changing locations of lesions from cemento-enamel junctions to occlusal fissures and interstitial contact areas (Corbett and Moore, 1976; Whittaker, 1993; Moore, 1993). Particularly marked increases in the frequencies of caries occurred in the latter half of the 19th century and these have been attributed to dramatic increases in the consumption of sugar and refined carbohydrates between 1830 and 1880 (Brothwell, 1959; Hardwick, 1960; Corbett and Moore, 1976; Moore, 1993). Nevertheless, there are some significant differences in reported frequencies of caries for samples from similar time periods and the explanations for these differences are not clear (Whittaker, 1993). As a result of methodological variations in the reporting and analyses of caries, it is difficult to identify the reasons for sample differences.

Substantial increases in caries also occurred in America in the latter half of the 19th century, which are attributed to the consumption of cariogenic foods. However, 19th century Americans are said to have eaten half the amount of sugar of their British counterparts (Deerr, 1950), and this is believed to be reflected in some caries differences between samples (Sutter, 1995). Difficulties arise again with the interpretations of inter-sample differences which are given a variety of explanations including sampling error, varying age composition of samples, sample biases, differences in infectious disease rates, and dietary differences (Sledzik and Moore-Jansen, 1991; Sutter, 1995). It is difficult to evaluate these explanations because of variations in the reporting of data (also noted by Whittaker, 1993, and Sutter, 1995). Reporting caries by individual allows evaluation of detailed intrasample variability, but both individual rates and total percent carious teeth may be affected by the age, sex composition, and size of the sample. Antemortem tooth loss, which is strongly affected by caries occurrence, is also variably reported in the literature and the effect of postmortem tooth loss on caries prevalence is often difficult to interpret from published data.

The present study reports on caries in a large sample of adult individuals from a 19th century cemetery located in southeastern Ontario. We attempt to provide a comprehensive survey of caries and antemortem tooth loss rates, examine the effects of age and sex on dental pathology, and compare these observations to other British and American historical samples. We also refer to stable carbon isotope data on bone collagen from this sample that may provide a measure of the consumption of cane sugar (Katzenberg et al., submitted).

Stable carbon isotope ratios differ in plants depending on their mode of photosynthesis (see Ambrose, 1993; Katzenberg, 1992, or Schwarcz and Schoeninger, 1991, for background information). These differences are passed on to human consumers and may be determined by analysing preserved protein (largely collagen) and carbon in biological apatite. Recent controlled feeding studies carried out on rodents (Ambrose and Norr, 1993; Tieszen and Fagre, 1993) demonstrate that the carbon in bone collagen is mainly derived from the protein component of the animal's diet while the carbon in biological apatite is more representative of the total diet, including carbohydrates such as sugar.

The diet of European migrants to Upper Canada during the 19th century was largely based on C_3 plants such as wheat and barley. Domesticated animals ate predominantly locally available C_3 plants and C_3 feed from wheat, barley, and oats. C_4 plants in the diet of the people included maize, in the form of corn meal used in breads, and sugar cane, used as a sweetener. Because maple trees, and thus maple sugar, are C_3, this form of sugar will not be distinguishable from the mainly C_3 diet. However, sugar from sugar cane may show up as a slight increase in δ^{13} C values in human bone. We assume, for this study, that maize consumption remained fairly constant. Our data at this time are from bone collagen. If humans can be as-

TABLE 1. *Summary of dental pathology sample*

Description	Cases	Remaining	%	N	%
Cases					
Adults in skeletal study	276	276	100		
Cases edentulous	31	245	89		
Cases fragmentary	16	229	83		
Maxilla only 6					
Mandible only 22					
Both jaws 201					
Teeth					
Total teeth expected (276 × 32)				8,832	
Total teeth expected of available jaws (207 maxillae × 16 teeth) = 3,312 + (223 mandibles × 16 teeth) = 3,568 + 267 sockets or teeth in fragmentary cases				7,147	
Actual sockets observed (due to indeterminate cases)				6,635	
Total teeth observed				4,605	69.4

sumed to be like rodents, then we might only expect to see a change in $\delta^{13}C$ due to sugar consumption from the analysis of bone apatite. Such analyses are planned but not completed. Here we report δ^{13} C from collagen to see if there is any increase over time that might reflect an increase in sugar consumption.

Finally, we examine documentary information about socioeconomic factors, diet, dental care, and environmental conditions that might have contributed to the observed rates of dental pathology in this skeletal sample.

MATERIALS AND METHODS

St. Thomas' Anglican Church in Belleville, Ontario, was founded in 1818 and its associated cemetery was used from 1821 to 1874 (Herring et al., 1994). The total burials in the cemetery numbered 1,564 of which 558 or 36% were represented by completely intact, observable skeletons (Saunders et al., 1995a). Of these, 282 (50.5%) were aged less than 15 years (Saunders et al., 1995b). Of the remaining 276 individuals, 229 cases had observable dentitions (Table 1). The remaining 47 cases do not bias the dental study by their exclusion since only 16 of them (6% of the total) were fragmentary. The remaining 31 cases were edentulous for one or both jaws.

The town of Belleville was settled by United Empire Loyalists (mainly British or American born) after the American Revolution as well as further waves of settlers from the United States after the War of 1812, again of mainly British origin. Further extensive waves of immigrants arrived in the area beginning in the 1830s and these were mostly from Britain (Herring et al., 1994; Saunders et al., 1995b).

The personal identities of the skeletons are unknown except for a subsample of approximately 80 individuals. Due to two fires at the church over the last two centuries, most tombstones were moved from their grave sites. However, the subsample of personally identified individuals was determined by comparison of legible coffin plates in the graves to listings of interments in the parish registers. In addition, since the names of all individuals interred in the cemetery are listed in the parish registers, it is possible to compare sampling distributions of skeletal analyses to parish register data (Saunders et al., 1991; Rogers, 1991; Herring et al., 1994; Saunders et al., 1995a, 1995b).

The sex of the documented individuals is known from their names. Of the unidentified skeletons, sex was determined in the majority of cases from intact morphological features of the bony pelvis (Rogers, 1991). A comparison and statistical test of the sex ratios of the skeletal sample and overall burial sample listed in the parish register showed no significant differences (Rogers, 1991). Also, tests of accuracy of morphologically determined sex from the pelvis using the documented sample were highly reliable yielding an accuracy rate of 99% (Rogers and Saunders, 1994).

Estimation of age-at-death of the adults was calculated using the following methods: pubic symphysis metamorphosis (following the smoothing method of Jackes, 1992) and changes to the auricular surface of the hip bone (Lovejoy et al., 1985). A number of

other methods have been employed for age estimation but they are not included in these estimates because of problems with sampling (morphological changes to the sternal rib) or because of their apparent unreliability for this sample (dental wear and cranial suture closure) (Saunders et al., 1991). Average age-at-death of adults estimated from the skeletons is 42.5 years, and the average age-at-death for the total adult burial sample in the cemetery taken from the parish registers is 47.9 years.

Initially, teeth were examined for presence, postmortem absence, antemortem absence, congenital absence, partial eruption, or no eruption. Determination of the presence or absence of carious lesions involved visual observation using a dental pick and a magnifying glass. The study was conducted in daylight by windows receiving direct sunlight, under overhead lighting, and with a manually angled desk lamp. Each tooth was examined visually for evidence of a black or necrotic site. Scoring was both overall and for specific surfaces, using a modification of Patterson's (1984) methods and rankings. These were used to indicate total number of lesions per tooth, size of destruction, and locations of lesions. The visual method of caries identification has previously been shown to be reliable when compared to both radiographic and histological studies (Whittaker et al., 1981) and to minimize interobserver error (Rudney et al., 1983).

Calculating caries' occurrence

To analyse caries occurrence by sex, age, tooth type, location, and total sample, Moore and Corbett (1971) have recommended calculating a Caries Rate *separately for each individual* by expressing the numbers of each tooth type carious as a percentage of the numbers of each tooth type present as with the following:

e.g. Caries Rate for incisors

$$= \frac{\text{number of carious incisors}}{\text{number of incisors present}} \times 100$$

$$\frac{\text{3 carious incisors}}{\text{total of 8 possible incisors present}} \times 100 = 37.5$$

An overall mean Caries Rate for a sample of individuals can be counted which is represented by the total number of carious teeth as a percentage of the total number of observable teeth per individual summed and then divided by the total number of individuals. Observing caries occurrence by individual is seen to be the logical approach when there is the possibility of considerable variation in caries experience among individuals within a population and because sample sizes might have a considerable effect upon calculations of the total proportion of carious teeth within any one sample.

In addition, because the majority of teeth lost antemortem are often lost due to caries (Harris, 1968; Menaker, 1980), the Diseased-Missing Index (DM Index) can be calculated by arch, tooth type, or total teeth. This index is calculated as the ratio of carious teeth and teeth lost antemortem, relative to the total number of teeth and resorbed sockets observed for each individual's dentition using the following equation:

DM Index

$$= \frac{\begin{array}{c}\text{total number of carious teeth}\\ \text{and number of restored sockets}\end{array}}{\begin{array}{c}\text{total number of teeth}\\ \text{and resorbed sockets}\end{array}} \times 100$$

The majority of researchers report the presence of caries in skeletal samples as the total number of carious teeth as a proportion of the total observable teeth in the sample (referred to here as Total Percent Caries) rather than by individual. These values are also reported here.

Another way of dealing with the reporting of caries when sample sizes are small, but still confining observations to individuals, is to report average caries rates per mouth, or the absolute numbers of carious lesions observed per intact teeth per individual (Rathbun, 1987) rather than as a proportion as Corbett and Moore have proposed. This value does not control for differences in the numbers of observable teeth from individual to individual.

In order to determine whether there is a statistically significant difference in Caries Rates or DM Indices between males and females in the St. Thomas' sample while

TABLE 2. Teeth missing or affected by caries

Tooth	Sockets (N)	Postmortem loss N	Postmortem loss %	Antemortem loss N	Antemortem loss %	Intact teeth (N)	Carious teeth (N)	Observed teeth (%)
18	142	17	12.0	22	15.5	88	51	58.0
17	207	12	5.8	65	31.4	120	69	57.5
16	207	6	2.9	82	39.6	110	67	60.9
15	207	11	5.3	65	31.4	122	42	34.4
14	207	14	6.8	64	30.9	123	38	30.9
13	206	7	3.4	29	14.1	166	33	19.9
12	207	16	7.7	37	17.9	149	38	25.5
11	207	19	9.2	28	13.5	156	34	21.8
21	207	30	14.5	22	10.6	149	36	24.2
22	207	23	11.1	34	16.4	142	44	31.0
23	207	11	5.3	27	13.0	164	33	20.1
24	207	9	4.3	64	30.9	130	46	35.4
25	207	10	4.8	67	32.4	126	48	38.1
26	207	5	2.4	74	35.7	123	78	63.4
27	207	7	3.4	64	30.9	126	81	64.3
28	141	7	5.0	29	20.6	89	49	55.1
48	168	3	1.8	56	33.3	102	55	53.9
47	223	3	1.3	99	44.4	119	82	68.9
46	223	3	1.3	117	52.5	98	60	61.2
45	223	1	0.4	43	19.3	177	53	29.9
44	223	7	3.1	28	12.6	185	31	16.8
43	223	4	1.8	10	4.5	209	23	11.0
42	223	6	2.7	21	9.4	194	14	7.2
41	223	12	5.4	35	15.7	174	9	5.2
31	223	18	8.1	27	12.1	176	11	6.3
32	223	11	4.9	15	6.7	194	17	8.8
33	223	4	1.8	9	4.0	210	17	8.1
34	223	3	1.3	19	8.5	200	38	19.0
35	222	2	0.9	43	19.4	173	39	22.5
36	223	2	0.9	111	49.8	106	63	59.4
37	223	2	0.9	100	44.8	114	80	70.2
38	166	5	3.0	59	35.5	91	55	60.4
Maxilla Subtotal	3180	204	6.4	773	24.3	2083	787	37.8
Mandible Subtotal	3455	86	2.5	792	22.9	2522	647	25.7
Total	6635	290	4.4	1565	23.6	4605	1434	31.1

controlling for or removing the effect of a relationship between age and increasing caries, a two-way analysis of covariance was calculated on the individual Caries Rates using sex as the independent variable and age as the covariate.

In a related study (Katzenberg et al., submitted) over 450 individuals from the St. Thomas' sample were analysed for stable isotopes of carbon and nitrogen. For the present study, only 45 personally identified individuals are discussed since their dates of death are known. Infants and young children were not included in the analysis since infants show greater variation in $\delta^{13}C$ values than do adults from the same sample (Katzenberg et al., 1993). If increased caries prevalence over time is due to increased sugar consumption, then this may be evident in the carbon isotope data.

RESULTS

Of the 6,635 observable sockets, 290 were lost postmortem (4.4%). Postmortem tooth loss proved to be much greater in the maxilla (N = 204 teeth lost) than in the mandible (N = 86 teeth lost). The teeth lost most frequently were maxillary central and lateral incisors, maxillary third molars, and mandibular central incisors (Table 2). Nevertheless, postmortem tooth loss is relatively low in this sample. Antemortem tooth loss ranges from 5% to 53% for any one tooth type with the highest values being observed for the first mandibular molars, all other molars, and the premolars.

The numbers of carious teeth are variable but relatively common ranging from 5% to 70% with highest values in the maxillary and mandibular molars. The percentages for caries

TABLE 3. St. Thomas' caries and antermortem tooth loss by sex

Tooth	Total sockets	Antemortem loss		Observed teeth	Carious		Tooth	Total sockets	Antemortem loss		Observed teeth	Carious	
		N	%		N	%			(N)	%		N	%
Adult Females													
Maxilla							Mandible						
18	63	10	15.9	42	22	52.4	48	67	20	29.9	46	25	54.3
17	88	30	34.1	52	31	59.6	47	96	49	51.0	45	36	80.0
16	86	32	37.2	51	37	72.5	46	95	56	58.9	38	27	71.1
15	88	28	31.8	53	21	39.6	45	98	24	24.5	73	29	39.7
14	90	28	31.1	53	17	32.1	44	96	12	12.5	80	19	23.8
13	91	17	18.7	71	15	21.1	43	97	6	6.2	90	11	12.2
12	89	16	18.0	64	23	35.9	42	96	7	7.3	86	6	7.0
11	96	14	14.6	67	22	32.8	41	98	14	14.3	81	5	6.2
21	89	9	10.1	64	22	34.4	31	98	11	11.2	78	6	7.7
22	88	17	19.3	59	26	44.1	32	96	6	6.3	86	9	10.5
23	90	10	11.1	72	19	26.4	33	98	5	5.1	91	9	9.9
24	91	28	30.8	60	25	41.7	34	97	10	10.3	85	22	25.9
25	90	32	35.6	56	28	50.0	35	95	22	23.2	72	23	31.9
26	90	29	32.2	59	39	66.1	36	96	53	55.2	42	29	69.0
27	83	30	36.1	50	31	62.0	37	96	50	52.1	44	36	81.8
28	57	10	17.5	41	22	53.7	38	71	22	31.0	46	26	56.5
Subtotal	1369	340	24.6	914	400	45.3		1490	367	24.9	1083	318	36.8
Total	2859	707		1997	718	41							
Adult Males													
Maxilla							Mandible						
18	84	12	14.3	60	29	48.3	48	101	36	35.6	62	30	48.4
17	109	35	32.1	68	38	55.9	47	125	50	40.0	74	46	62.2
16	112	50	44.6	59	30	50.8	46	123	61	49.6	60	33	55.0
15	110	37	33.6	69	21	30.4	45	124	19	15.3	105	24	22.9
14	113	36	31.9	70	21	30.0	44	124	16	12.9	105	12	11.4
13	111	12	10.8	95	18	18.9	43	125	4	3.2	118	12	10.2
12	113	21	18.6	85	15	17.6	42	124	14	11.3	107	8	7.5
11	113	14	12.4	89	12	13.5	41	123	21	17.1	93	4	4.3
21	112	13	11.6	85	14	16.5	31	123	16	13.0	98	5	5.1
22	111	17	15.3	83	18	21.7	32	124	9	7.3	108	8	7.4
23	114	17	14.9	94	14	14.9	33	125	4	3.2	119	8	6.7
24	112	36	32.1	70	21	30.0	34	125	9	7.2	115	16	13.9
25	113	35	31.0	70	20	28.6	35	123	21	17.1	101	16	15.8
26	112	45	40.2	64	39	60.9	36	122	58	47.5	63	33	52.4
27	113	33	29.2	76	50	65.8	37	120	50	41.7	70	44	62.9
28	87	19	21.8	61	27	44.3	38	96	37	38.5	55	29	52.7
Subtotal	1739	432	24.6	1198	387	34.3		1927	425	22.6	1453	328	27.4
Total	3666	857	23.6	2651	715	30.9							

for each tooth type are generally higher in the maxilla than in the mandible. The percentages for caries listed in Table 2 are proportions of the total number of observable intact teeth.

The percentages of caries out of all observable teeth for males and females are presented in Table 3. Here again, caries is highest in the molar and premolar teeth and higher in the maxillary arch. Caries appears to be higher in females than in males. This observation is confirmed by reporting the average number of carious lesions by sex per mouth as seen in Table 4. Females have significantly higher numbers of carious lesions per mouth than do males but the difference between the sexes in absolute numbers of teeth lost before death is not significant.

TABLE 4. Average absolute number of carious lesions and antemortem teeth lost per mouth

	Mean[1]	S.E.	S.D.	N
Females				
Carious lesions	7.05	0.54	5.46	102
Antemortem loss	7.07	0.63	6.36	102
Males				
Carious lesions	5.63	0.35	3.97	127
Antemortem loss	6.65	0.47	5.24	127

[1] Mann-Whitney U test for sex differences for caries $P = .142$. Mann-Whitney U test for sex differences for antemortem loss $P = .997$.

Table 5 lists the summary data for St. Thomas' males and females for Caries Rate and DM Indices by tooth type and arch. The mean age at death for the 102 adult females is 42.1 years and the mean age at death for

TABLE 5. Summary of caries rates and diseased-missing indices

	Females	Males
Number of individuals	102	127
Mean skeletal age at death	42.1	45.6
Number of teeth	1997	2651
Number of carious teeth	718	715
Number of resorbed sockets	707	857
Overall Caries rate	34.53 (S.E. = 2.29)	28.26 (S.E. = 1.74)
Overall Diseased missing index	53.66 (S.E. = 2.35)	47.12 (S.E. = 1.93)
Diseased missing index by tooth type		
Incisors	31.83 (S.E. = 3.27)	26.40 (S.E. = 2.68)
Canines	25.65 (S.E. = 3.13)	21.39 (S.E. = 2.57)
Premolars	52.00 (S.E. = 3.36)	41.77 (S.E. = 2.70)
Molars	80.47 (S.E. = 2.39)	74.73 (S.E. = 2.01)
Diseased missing index by arcade		
Maxillary arcade	53.61 (S.E. = 3.26)	46.33 (S.E. = 2.49)
Mandibular arcade	46.71 (S.E. = 2.37)	39.18 (S.E. = 2.04)

the 127 St. Thomas' males is 45.6 years. This table also summarizes the total numbers of observable teeth, numbers of carious teeth and numbers of resorbed sockets as can be found in Tables 4 and 5. These illustrate the high overall proportions of caries and antemortem tooth loss for both males and females.

For all teeth and sockets observed, females have a mean Caries Rate of 34.53 and a mean DM Index of 53.66, whereas males have a mean Caries Rate of 28.26 and a mean DM Index of 47.12. The discrepancy between the two indices indicates that the Caries Rate may underestimate total caries and the DM Index may overestimate it as noted by Lukacs (1995). However, previous authors have utilized the DM Index as the indicator of caries (Kelley et al., 1991; Sutter, 1995) based on clinical evidence that the loss of teeth antemortem is directly related to carious destruction. This assumption is probably appropriate in those populations not experiencing heavy wear, severe periodontal disease, or extensive tooth trauma, as is the case for the St. Thomas' sample.

Based on the data presented in Table 5, females display a higher overall Caries Rate and a higher DM Index than males for all tooth types and both arches. In addition, as might be expected, posterior teeth show higher values for the DM Index than do anterior teeth. The results of the analysis of covariance where sex is the independent variable and age is the covariate were calculated after transforming the Caries Rate and DM Index values for each individual using a square root transformation, since the values for these statistics are not normally distributed. The results are presented in Table 6. Age at death was found to be significantly related to both caries rate and diseased teeth and teeth missing before death. When age is accounted for, there is no significant difference between the overall Caries Rate of males and females ($P = 0.298$). However, even when age is accounted for, there is still a significant difference between the DM Index of males and females ($P = 0.023$) with females showing higher DM Indices than males.

TABLE 6. Analysis of covariance for caries rate and DM[1] index for sex and age[2]

Source	Sum of squares	DF	Mean square	F ratio	*P* value
Caries Rate					
Sex	10.01	1	10.01	3.92	.049
Age	3.80	1	3.80	1.49	.224
Error	503.00	199	2.55		
DM Index					
Sex	19.13	1	19.13	8.41	.004
Age	63.24	1	63.24	27.79	.000
Error	480.15	213	2.28		

[1] DM = Diseased-Missing.
[2] Sex is the independent variable and age is the covariate.

Stable carbon isotope ratios in the people buried in St. Thomas' Church cemetery show little variation. For the 45 individuals over the age of 4 years at death, the mean $\delta^{13}C$ value is -19.5 with a range of -21.8 to -18.0. These numbers are characteristic of a largely C_3 based diet with some C_4 based plants. A comparison of males and females aged 4 years and older shows no significant difference between the sexes. Eighteen females have a mean value of $-19.6 \pm 0.8‰$ in comparison to 26 males with a mean value of

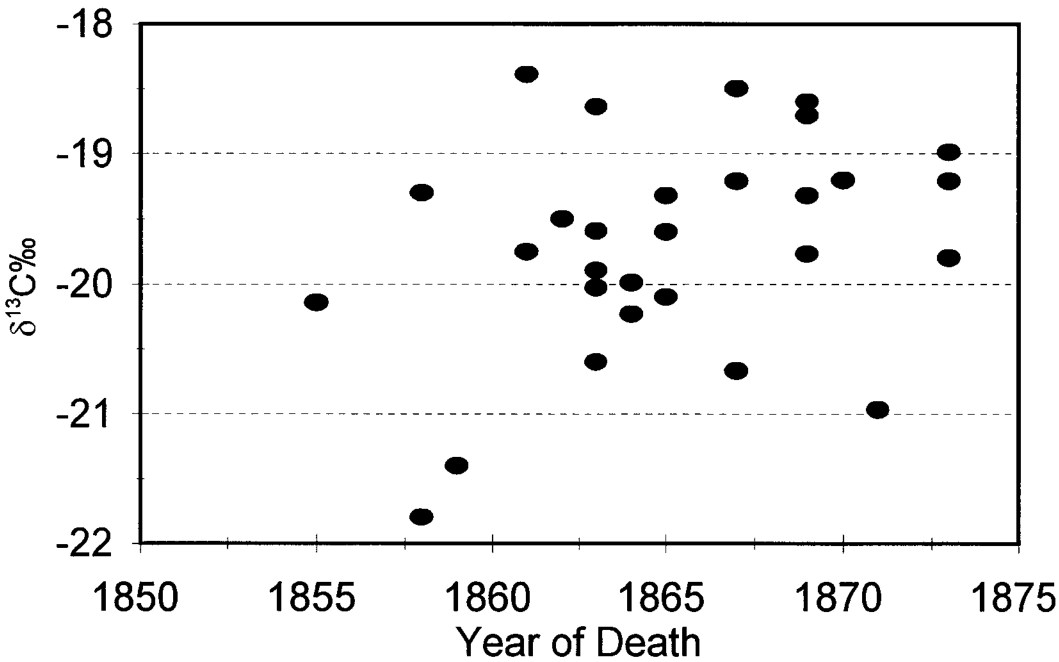

Fig. 1. Plot of $\delta^{13}C$ values against year of death for sample of personally identified individuals.

$-19.4 \pm 0.8‰$. The difference is not statistically significant. Individuals aged over 12 years (those with their permanent dentition) were analysed to compare $\delta^{13}C$ values and year of death. Results of regression analyses indicate a weak positive relationship with $r = 0.338$ and $P = 0.067$. Figure 1 shows this weak trend towards increasing (less negative) $\delta^{13}C$ values from 1850 to 1880.

DISCUSSION

The etiology of dental caries

Dental caries is a pathological process of localized dissolution of the mineral phase of tooth tissues by organic acids produced by bacterial fermentation (Newbrun, 1982). The development of dental caries involves three important components: the presence of microorganisms in dental plaque, susceptible tooth structure, and a cariogenic diet. Research into the epidemiology of dental caries has established that the most important dietary factor contributing to caries risk is fermentable carbohydrate, especially sugar (Winter, 1990). The presence of sugar around plaque-covered tooth surfaces has been shown to be essential for even the most minimal levels of caries formation (Rugg-Gunn and Edgar, 1984). Newbrun's 1982 summary of the literature has shown that of all the sugars, sucrose appears to be the most cariogenic based on research showing the most rapid metabolism of the simple sugars by bacteria, studies of experimental caries in animals, and clinical and epidemiological observations of the relationship between sucrose intake and caries prevalence.

Dietary sugar is the primary factor associated with caries prevalence but recent studies have also observed substantial declines in caries in areas with and without fluoridation, despite the fact that there are concomitant increases in the consumption of caloric sweeteners (Winter, 1990). Apparent changes in dental hygiene practices and the treatment of community water supplies in industrialized countries are considered by some to be insufficient explanations for this trend (Winter, 1990). This phenomenon of a caries decrease without dietary changes emphasizes that the mechanisms controlling caries prevalence in population groups are complex.

Diet and dental health in 19th century Belleville

Canadian pioneering settlers in the 19th century had an abundance of food. Although often cash poor, people were said to never be at risk of starvation because of the cheapness and profusion of daily fare. Abonyi (1993) has reconstructed the Belleville diet of the mid-19th century based on historic sources. She notes that meat (pork, beef, and mutton), bread, and vegetables were the dietary staples, with sweet, baked goods also being popular. Three meals a day were generally served with little variance in the composition of the recipes or methods of preparation. Canadian settlers also took advantage of North American foods, particularly maple sugar, maize, used primarily as corn meal flour, pumpkins, and wild fruits.

Abonyi also analysed ingredients and cooked stews, breads and vegetables for their chemical composition. The highest (least negative) $\delta^{13}C$ values were found in baked goods which include either or both of the main C_4 food sources, maize and cane sugar. Vegetable foods are exclusively C_3 and meats indicated animals feeding on C_3 plants.

It is difficult to obtain information on the composition and quantities of basic food groups in the daily diet in 19th century Belleville but there are some excellent primary sources from which we can construct a clearer picture of the relative importance of different foods. The most valuable of these is the collection of letters written by William Hutton, settler in Belleville, to his mother in Ireland from 1834 to 1858 (Boyce, 1972). Hutton's letters contain many references to food, and since he was a farmer with a strong interest in agricultural developments they also contain details about the success and failure of various crops, the quality of food production and the family's experiments with novel North American agricultural practices (Boyce, 1972). These letters provide some indication of the relative importance of carbohydrates and particularly sugar in the diet of Belleville residents.

A lot of meat was eaten but the lack of refrigeration meant that most meats could only remain fresh for a few days in the warm months and often the lack of winter fodder necessitated early butchering of farm animals and the eating of cured meats. People ate these cured or partially fresh meats with large amounts of sweetened fruit preserves or pickles. In the summer, wild and cultivated fruits were eaten as a main meal with sugar, cooked sweetened flour, and milk, eaten as a type of porridge (Boyce, 1972).

The high consumption of foods prepared with refined flour which makes for softer, stickier breads and cakes is also implicated in the rise in caries in Britain in the 19th century (Moore, 1993). Most 19th century sources note the great importance of bread in the diet, even for homesteaders. William Hutton informed his mother in 1836 that "bread is our principal support" (Boyce, 1972, pp. 50). The heavy reliance on bread by the settlers, in addition to the use of corn meal porridge, cooked, sweetened flour mixtures and stewed, sweetened fruits probably contributed to the cariogenicity of the diet. While ceramic rollers for producing highly refined flour were not introduced to North America until after 1875 (Leung, 1981) the quality of stone ground flours varied greatly and Hutton noted that even the family's own locally ground flour produced bread nearly as soft and fine as that from the bakers in Belleville. The bran (and other leavings containing grit) that was produced from the grinding of the flour was fed to the livestock (Boyce, 1972).

Dental treatment and hygiene in 19th century Canada

The historical background for dental practice in North America derives mainly from France and England. The French were ahead of most other countries in the field of dentistry and many French-trained practitioners arrived in the United States at the end of the 18th century to act as preceptors for a whole field of American born dentists (Gullett, 1971).

One of these individuals was G.V.N. Relyea, born in Albany, New York, in the early 1800s, who attended lectures at the Albany Medical College and later studied dentistry for a year with a practising dentist (Gullet, 1971). Relyea settled in Belleville in 1843

where he practiced until 1874, commanding control over patients from a wide area. Relyea, as would have most 19th century dentists, offered to extract, restore, regularise and replace teeth, to prepare dental plates and to treat periodontal disease (Hillam, 1991).

Nevertheless, there were limits imposed on these practitioners since there were no anaesthetics, they used hand instruments and relatively unsophisticated materials and most important, there was a lack of knowledge of the etiology and pathology of dental disease. Consequently, preventive and community dentistry practises hardly existed and what services Relyea would have offered would be limited by their cost and the ability of the patients to pay. Of the 229 adults in the St. Thomas' skeletal sample with intact dentitions, 18 were observed to have tooth restorations, either of mixed silver amalgams or gold. These included 12 males and eight females of varying ages possessing from one to six restorations per mouth.

Generally though, levels of dental hygiene were not high in mid-19th century Belleville. Based on general accounts of the history of oral hygiene and the history of the toothbrush it appears that regular tooth cleaning was not a widespread practise (Asbell, 1992). Although France and England were the major manufacturers of toothbrushes in the 18th century, they remained luxury items because of the cost of production until the late 1860s (Mattick, 1992).

Other factors contributing to cariogenicity

The cariostatic properties of fluorine compounds are well known (Harris, 1968). Fluoridation was not introduced until the 20th century and natural soil fluorine levels in the North American northeast are some of the lowest on the continent (Shaw, 1985). Fluorine is virtually absent from the waters of Lake Ontario and levels in area streams are negligible (Thomas, 1954). Belleville residents in the 19th century took their water from naturally flowing springs (Moodie, 1853; Boyce, 1972) and consequently would not have ingested fluorides in any significant amounts.

Sugar consumption

The dramatic increase in sugar consumption in Britain from the mid-19th through to the 20th centuries is a well-described phenomenon (Drummond and Wilbraham, 1939; Hardwick, 1960; Burnett, 1966). Both the British and the Americans are said to have doubled their consumption of processed sugar during the mid-19th century (Deerr, 1950; Kolodny, 1976 cited in Sledzik and Moore-Jansen, 1991) but the British are reported to have eaten twice as much sugar as their American counterparts (Deerr, 1950).

Since the majority of 19th century Belleville residents were of British origin (particularly the Anglicans), we would expect these people to have followed the dietary habits of their relatives in England, Ireland, and Wales. The major source of sweetenings for 19th century North American and British consumers was cane sugar originally produced in the West Indies. But almost equal in importance in Canada was the production of maple sugar. In the 1830s and 1840s the cost of cane sugar tended to be a little higher than at home (Boyce, 1972), so maple sugar was preferred. The predominance of cane sugar over maple increased in Canada in the 1860s and beyond (Gov't of Canada, 1864, 1871, 1881).

It is possible to estimate the probable per capita consumption of sugar in the Hutton family from William Hutton's letters. In addition, census returns and the annual sessional papers of the government of Canada report imports and exports of sugar for 1861, 1871, and 1881 (Gov't of Canada, 1864, 1875, 1883). Published figures are available for per capita consumption of sugar in Britain and the United States (Deerr, 1950; Burnett, 1966; Cummings, 1970). These data are presented in graph form in Figure 2.

While there is some disagreement over estimated consumption values for Britain, all sources agree that consumption rose dramatically in the latter half of the 19th century as tariffs on imports were removed. Estimates for the United States also show increases throughout the latter half of the century but the amounts in any decade are generally lower than those for Britain. The

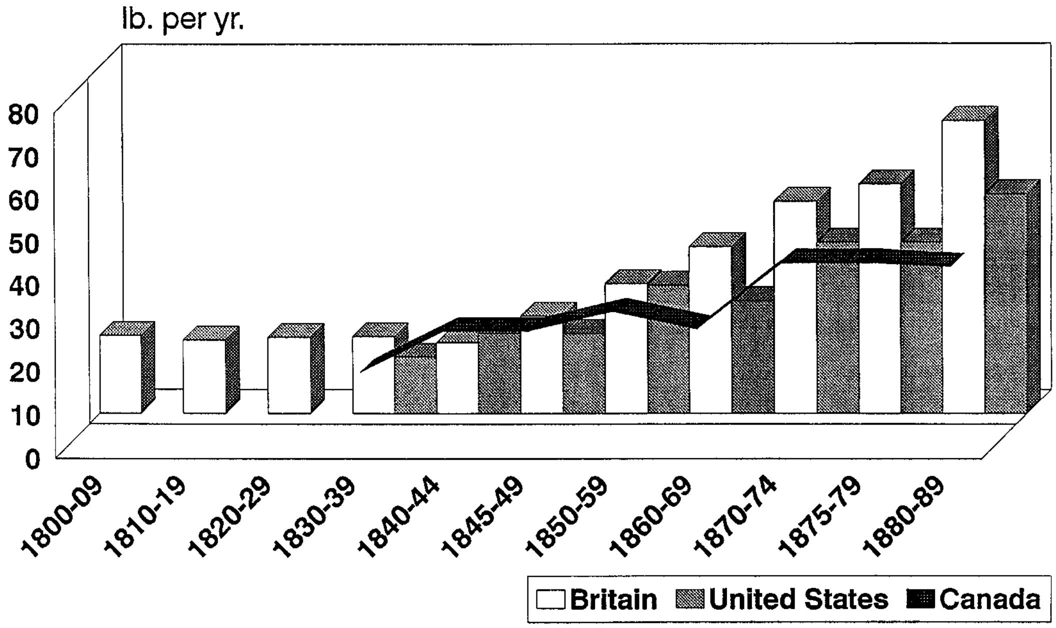

Fig. 2. Per capita sugar consumption calculations for 19th-century Britain, United States and Canada.

values estimated for Canada fluctuate around those for both Britain and the United States until the 1860s and then level off to values almost identical to those of the United States. Reported per capita sugar consumption in the three countries in 1933 is 106 lb for Britain, 100 lb for the United States and 93 lb for Canada (Deerr, 1950). However, caries prevalence in the St. Thomas' sample is closest to published values for British historical samples rather than American samples.

Results of the regression analysis of $\delta^{13}C$ values and year of death in the small sample of personally identified individuals (Fig. 1) shows a weak trend for increasing (less negative) values from 1850 to 1880. It is not possible to tell if this trend is due to increasing sugar consumption alone, or to increasing maize consumption. However, there is no historical reference to increasing maize consumption while the results follow the prediction that cane sugar (a C_4 sugar) increased during that period. Since sugar was used as a dietary supplement (e.g., sweetener and preservative) it would appear only as a subtle change in $\delta^{13}C$ values of collagen. As mentioned earlier, a further problem with relying on carbon isotope data from collagen is that because cane sugar is a carbohydrate, its isotope signature may not be well reflected in collagen. It is also possible that much of the sugar ingested was maple sugar. However, historical sources demonstrate clearly that the importation and use of cane sugar in Canada increased throughout the 19th century as prices dropped (Boyce, 1972; Canada, 1864, 1875, 1883).

Sample comparisons

There are only two other studies of historical samples which have published Caries Rates and DM Indices calculated for individuals. These are by Corbett and Moore (1976) (see also Moore, 1993) and Sutter (1995). Unfortunately, it is not possible to directly compare the results from the St. Thomas' sample to Corbett and Moore's study of 19th century English because their sample of skulls was divided into age groups on the basis of dental wear. However, Figure 3 presents the percentages for Caries Rate and DM Index (DM Index is not available

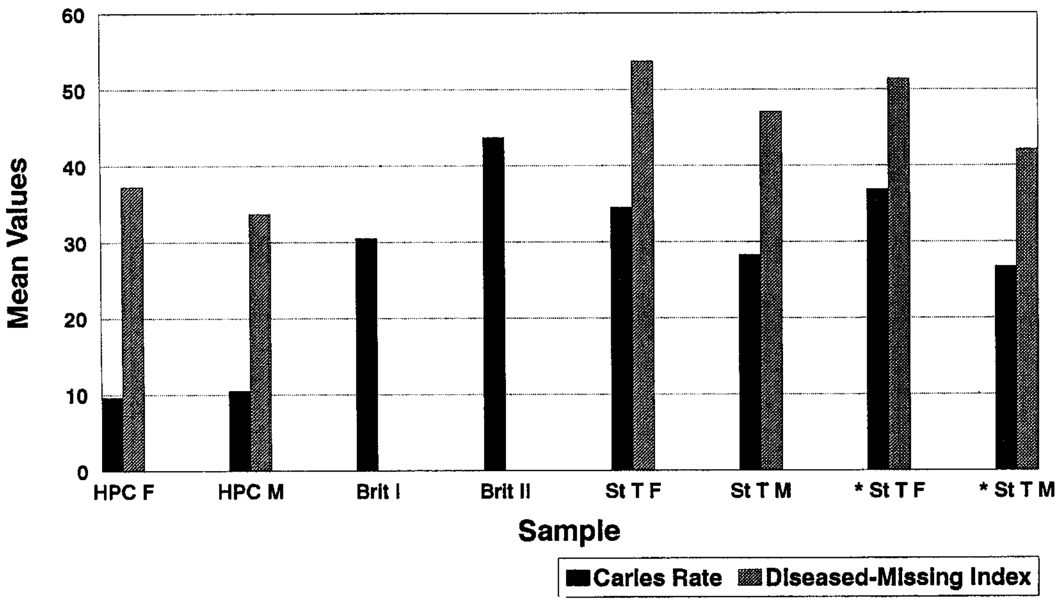

Fig. 3. Sample comparisons of Caries Rates and DM Indices for Highland Park sample, Ashton-under-Lyne British I (pre-1850) and II (post-1850) samples, total St. Thomas' sample, and *St. Thomas' sample selected for lower mean age-at-death.

from Corbett and Moore) for the three samples, the Highland Park Cemetery (HPC) (Sutter, 1995), the Ashton-under-Lyne Cemetery in northwest England, represented by burials before 1850 (Brit I) and after 1850 (Brit II) (Corbett and Moore, 1976), and the St. Thomas' Cemetery (St T). To allow for comparisons, Corbett and Moore's values for the last three dental wear stages were combined to calculate mean Caries Rates for all adults. The figure also includes two subgroups of the St. Thomas' Cemetery (St T M, males; and St T F, females) from which some older individuals were removed to reduce the mean ages at death for males and females to make them comparable to the Highland Park sample.

Caries Rates are low in the Highland Park sample compared to the British and Canadian samples. The DM Index in the St. Thomas' sample is also markedly higher than that for the Highland Park sample. When male and female subsamples of the St. Thomas' sample (St T M and St T F) with age distributions equivalent to the Highland Park sample are compared the Caries Rates and DM Indices are still noticeably higher in the St. Thomas' subsample.

TABLE 7. Comparison of mean caries rates reported by tooth type in the Ashton-under-Lyne 19th century British[1] and St. Thomas' samples

	British I Range of means	British II Range of means	St. Thomas' Range of means[2]
Incisors	7–21	21–38	5–25
Canines	16–19	25–30	8–19
Premolars	22–32	38–48	16–38
Molars	38–57	56–74	49–70

[1] The Ashton-under-Lyne sample reported by Corbett and Moore (1976) was divided into an 1800–1850 (British I) and an 1850–1900 (British II) sample.
[2] Reported as a range of mean caries rates because the British samples are only reported graphically separated by tooth type and attrition stage.

The Caries Rates in the St. Thomas' sample appear to be closer to the pre-1850 British sample than the post-1850 British sample. This is supported by a comparison of the ranges of mean Caries Rates reported for each tooth type in the three adult attrition age groups in the British samples to the reported percent ranges for tooth types in the St. Thomas' sample (Table 7). Since Corbett and Moore only report mean Caries Rates for the four teeth in a quadrant of any particular tooth type (i.e. first molars) it is necessary to look at the range of means for

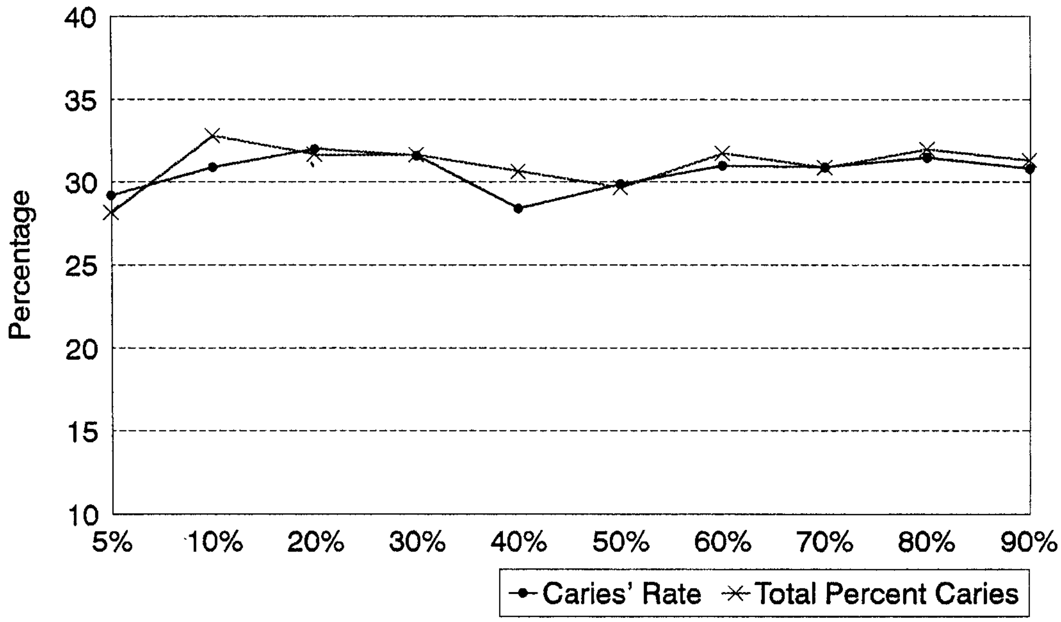

Fig. 4. Comparison of Caries Rate to Total Percent Caries calculated from random samples, ranging from 5% to 90% of the total sample of the St. Thomas' dentitions.

each tooth type from their sample. When this is done, only the rates for the molar teeth of the St. Thomas' sample show substantial overlap with the post-1850, or British II sample.

While reporting the prevalence of caries and/or antemortem tooth loss by individual (Caries Rate and Diseased Missing Index) is a useful method for investigating samples, Total Percent Caries values (the total number of caries/total number of observable teeth in a sample) are often relatively close to Caries Rates. Factors that would affect the differences between these two statistics are poor preservation of observable tooth positions and a strong negative correlation between the number of carious teeth and the number of total observable teeth present in any one individual. That is, if individuals who have lost many teeth tend to have more caries, then their individual Caries Rates will be much higher than those of other individuals in the sample, creating greater variability in the frequency distributions of Caries Rates. A negative correlation between carious teeth and total teeth present in the St. Thomas' sample was found but the coefficient is not significant ($r = -.025$, $P = .712$). When a series of random samples was selected from the St. Thomas' dentitions, ranging from 5% to 90% of the total sample, the differences between calculated mean Caries Rates and Total Percent Caries for each sample were found to be relatively close (Fig. 4). Consequently, Total Percent Caries values and Antemortem Tooth Loss values were compared in a series of historical samples reported from the literature (Fig. 5). The result shows that the caries values for the St. Thomas' and the British series are the highest of all reported samples. It is unfortunate that some of the studies do not report antemortem tooth loss values so that a broader picture of sample differences in dental pathology could be examined. However, since there is a strong association between the occurrence of caries and antemortem tooth loss, the above observations probably still hold.

The comparisons presented in Figures 3 and 5 place the St. Thomas' sample closest to the British series in terms of occurrence of caries, particularly to the pre-1850 (or Brit 1) subgroup. Caries values reported for the

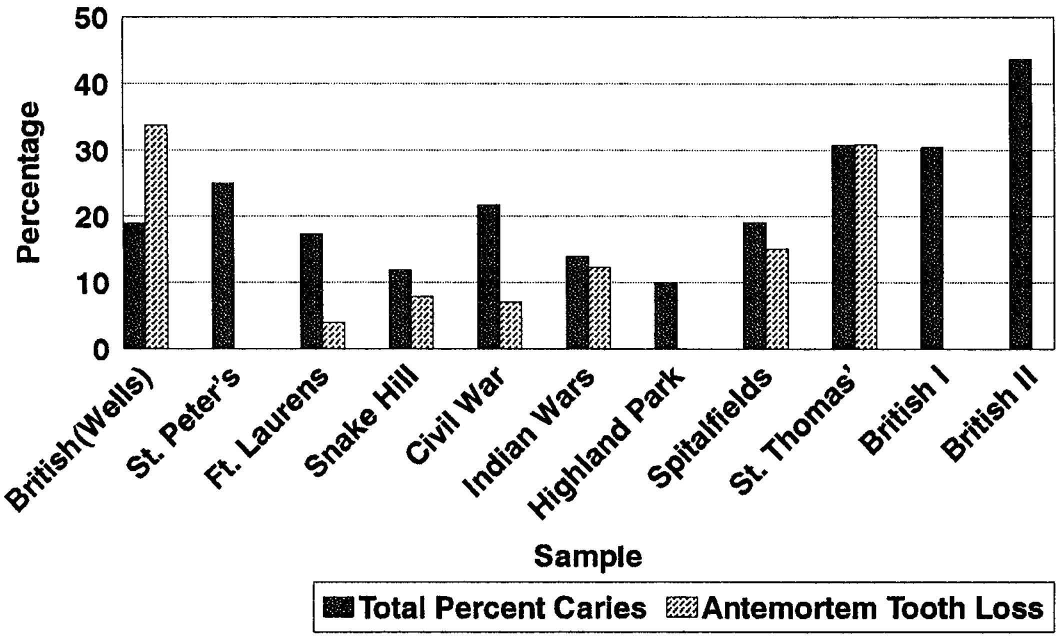

Fig. 5. Inter-sample comparisons of Total Percent Caries and Antemortem Tooth Loss for a number of 18th and 19th century skeletal samples.

British series by Wells (1968) are lower as are those for the Spitalfields' sample from London (Whittaker, 1993). However, both of these samples date to earlier times in the 17th, 18th and early 19th centuries. It is likely that these earlier groups represent individuals whose diets contained relatively low amounts of processed foods, particularly refined sugars.

Except for the St. Peter's sample (Owsley et al., 1987), caries values are much lower in the American samples. Temporal or group selection factors may be important in explaining any differences. Sledzik and Moore-Jansen (1991) interpret the figures for the American military samples as indicating low carbohydrate diets in the earliest Snake Hill group, higher carbohydrate diets, and additional dental stresses affecting the Civil War group along with recruit selection to eliminate men with carious lesions.[1] The lower value of caries in the Indian Wars group is explained by the age structure of the sample and possible dietary differences. The 18th century St. Peter's sample comes from New Orleans where the highly cariogenic diet of cane sugar, corn meal, fine flour, and molasses contributed to high dental pathology statistics by worldwide standards (Owsley et al., 1987). Yet, caries in this group is still not as high as that for the St. Thomas' or British samples.

The Highland Park sample represents residents of the early 19th century Monroe County Poorhouse in Rochester, New York. The specific diets of these individuals are not known but the impact of a developing 19th century cariogenic diet is thought to be present (Sutter, 1995). While it is not possible to calculate percent antemortem tooth loss for all teeth in the Highland Park sample, Sutter's published values for DM Indices show that antemortem tooth loss when added to Caries Rates still do not exceed those for either the overall or even the age-adjusted St. Thomas' sample (see Fig. 3). Consequently, there were probably differences in the cariogenicity of the diets between the St. Thomas' and Highland Park people.

[1]In 1863–64, loss of teeth was the fourth highest cause for rejection for military draft into the Union Army (Lewis cited in Graves and Stamm, 1985).

The estimates of per capita sugar consumption for the United States, Britain, and Canada in the 19th century do not resolve these comparisons. Sugar consumption is not as high in 19th century Canada as in Britain and yet the St. Thomas' caries occurrence is considerably higher than that of the United States samples, even when antemortem tooth loss can be taken into account. The weak relationship between $\delta^{13}C$ values and year of death provides inconclusive support for increasing cane sugar consumption in Belleville through the latter half of the 19th century. It is possible that other dietary factors such as food consistency, preparation, frequency of eating, etc. might contribute to the high levels of caries in the St. Thomas' sample. Certainly, it has been demonstrated that age has a significant impact on the occurrence of caries in the sample and this was also shown by Sutter (1995) for the Highland Park sample. Consequently, caution is necessary to prevent over interpretation of the sample comparisons. While an attempt was made to compare the St. Thomas' and Highland Park samples with similar age structures (Fig. 3) this is not possible for most published studies. Skeletal collections are often very small, as is the case for two recently published 19th century skeletal samples from Texas and Illinois (Winchell et al., 1995; Larsen et al., 1995).

From a broader perspective it should be noted that caries prevalence in the United States has long been reported as highest in the northeast (Mandel, 1993). Part of the explanation comes from the fact that molasses, which was produced in the West Indies, was sent to the New England states to be converted to rum (Mintz, 1985). This practise continued throughout the 18th century and thereby contributed to regional dietary variations in the United States. But, high caries rates in the American Northeast have prevailed until the present day, and there appears to be no clear explanation for this persistence unless perhaps it is due to the continued effect of a regional cuisine or to the very low levels of natural fluorides in the area (Graves and Stamm, 1985; Mandel, 1993). It may be that the high levels of caries in the St. Thomas' sample are partly attributable to geography.

The observation that females have significantly higher Caries Rates and DM Indices, even when controlling for age, is in contrast to the observations of Sutter (1995), who found age to be a sufficient explanation for any variation in DM Indices in the Highland Park sample. Since the sex difference is not simply due to a higher proportion of older females other explanations should be sought. The analysis of carbon stable isotope ratios does not provide support for a dietary difference between the sexes. Whether womens' usual role in food preparation and their continuous access to food throughout the day is sufficient explanation is not clear at this time.

CONCLUSIONS

This study demonstrates that the occurrence of caries and antemortem tooth loss are high in the 19th century skeletal sample from St. Thomas' Church, Belleville, in eastern Canada. While females do not have significantly higher Caries Rates than males when the effect of age is controlled the addition of antemortem tooth loss values results in significantly higher DM Indices in females in the sample in spite of the additional effect from age. What is required are further investigations of large historical samples where it is possible to statistically compare consistently reported data. Particularly interesting would be further late 19th century data from the American northeast and late 19th century samples from Britain. We are also pursuing studies of carbon isotopes in biological apatites, which may provide a stronger signal for C_4 carbohydrates in the diet. Until such research is carried out, it will be extremely difficult to interpret inter-sample caries experience or the relative importance of various dietary and nondietary factors in the production of caries over the short time period represented by the existing historical samples.

ACKNOWLEDGMENTS

We thank Tracy Rogers, Gerry Boyce, and Sylvia Abonyi for their assistance with various phases of this study. We also thank St. Thomas' Anglican Church, Belleville for initial permission to study the remains and Heather McKillop for initiating the skeletal

project. Stable isotope analysis was carried out in the Stable Isotope Laboratory, Department of Physics, University of Calgary under the direction of H.R. Krouse. Staff of the Ontario Agricultural Museum, the Canada West Indies Molasses Company, the Ontario Ministry of Natural Resources, and Belleville Public Waterworks were instrumental in offering helpful reference information. Thanks also go to Ann Herring for her discussions on historical background and to Jerry Cybulski for reading and commenting on the manuscript.

LITERATURE CITED

Abonyi S (1993) The Effects of Processing on Stable Isotope Levels and Mineral Concentration in Foods: Implications for Paleodietary Reconstruction. Unpublished master's thesis, University of Alberta.

Ambrose SH (1993) Isotopic analysis of paleodiet: Methodological and interpretive considerations. In MK Sandford (ed.): Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology. Langhorne, PA: Gordon and Breach, pp. 59–130.

Ambrose SH and Norr L (1993) Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In JB Lambert and G Grupe (eds.): Prehistoric Human Bone: Archaeology at the Molecular Level. Berlin: Springer-Verlag, pp. 1–37.

Angel JL (1976) Colonial to modern skeletal change in the U.S.A. Am. J. Phys. Anthropol. *45:*723–736.

Angel JL, Kelley JO, Parrington M, and Pinter S (1987) Life stresses of the Free Black community as represented by the First African Baptist Church, Philadelphia, 1823–1841. Am. J. Phys. Anthropol. *74:*213–229.

Asbell MB (1992) Research in dental caries in the United States: 1820–1920. Compend. Contin. Educ. Dent. *14:*792–798.

Boyce G (1972) Hutton of Hastings. Belleville, Ontario: Mika and Mika.

Brothwell DR (1959) Teeth in earlier human populations. Proc. Nutr. Soc. *18:*59–64.

Burnett J (1966) Plenty and Want: A Social History of Diet in England from 1815 to the Present Day. Harmondsworth, Middlesex, England: Penguin.

Canada. Bureau of Agriculture and Statistics (1864) Census of the Canadas 1860–61. Vol. II. Agricultural Produce, Mills, Manufactories, Houses, Schools, Public Buildings, Places of Worship, etc.

Canada. Department of Agriculture (1875) Census of Canada 1870–71. Vol. III Table No. XXIII Field Products.

Canada. Department of Agriculture (1883) Census of Canada 1880–81. Vol. III Table No. XXIV Field Products.

Colyer F (1922) The teeth of Londoners of the 17th and 18th centuries. Dent. Rec. *42:*237–243.

Corbett ME, and Moore WJ (1976) Distribution of dental caries in ancient British populations. IV. The 19th century. Caries Res. *10:*401–414.

Cummings RO (1970) The American and His Food: A History of Food Habits in the United States. Chicago: University of Chicago Press.

Deerr N (1950) The History of Sugar. Vol. 2. London: Chapman and Hall.

Drummond JC, and Wilbraham A (1939) The Englishman's Food. London: Jonathan Cape.

Graves RC, and Stamm JW (1985) Oral health status in the United States: Prevalence of dental caries. J. Dent. Educ. *49:*341–351.

Gullet DW (1971) History of Dentistry in Canada. Toronto: Canadian Dental Association.

Hardwick JL (1960) The incidence and distribution of caries throughout the ages in relation to the Englishman's diet. Br. Dent. J. *108:*9–17.

Harris RS (1968) Art and Science of Dental Caries Research. New York: Academic.

Herring DA, Saunders SR, and Boyce G (1994) Bones and burial registers: Infant mortality in a 19th century cemetery from Upper Canada. Coun. for Northeast Hist. Arch. J. *20:*54–70.

Hillam C (1991) Brass Plate and Brazen Impudence: Dental Practice in the Provinces 1755–1855. Liverpool: Liverpool University Press.

Jackes M (1992) Paleodemography: problems and techniques. In SR Saunders and MA Katzenberg (eds.): The Skeletal Biology of Past Peoples: Advances in Research Methods. New York: Wiley-Liss, pp. 189–224.

Katzenberg MA (1992) Advances in stable isotope analysis of prehistoric bones. In SR Saunders and MA Katzenberg (eds.): The Skeletal Biology of Past Peoples: Research Methods. New York: John Wiley and Sons, pp. 105–120.

Katzenberg MA, Saunders SR and Fitzgerald WR (1993) Age differences in stable carbon and nitrogen isotope ratios in a population of prehistoric maize horticulturists. Am. J. Phys. Anthropol. *90:*267–281.

Katzenberg MA, Saunders SR, and Abonyi S (submitted) Bone chemistry, food and history: a case study from 19th century Upper Canada. In SH Ambrose and MA Katzenberg (eds.): Close to the Bone: Biogeochemical Approaches to Paleodietary Analysis in Archaeology, Plenum Press Series, Advances in Archaeological and Museum Science.

Kelley MA, Levesque DR, and Weidl E (1991) Contrasting patterns of dental disease in five early northern Chilean groups. In MA Kelley and CS Larsen (eds.): Advances in Dental Anthropology. New York: Wiley-Liss, pp. 203–214.

Lanphear KM (1988) Health and Mortality in a Nineteenth Century Poorhouse Skeletal Sample. Ph.D. dissertation, State University of New York, Albany.

Larsen CS, Craig J, Sering LE, Schoeninger MJ, Russell KF, Hutchinson DL, and Williamson MA (1995) Cross Homestead: Life and death on the Midwestern Frontier. In AL Grauer (ed.): Bodies of Evidence: Reconstructing History through Skeletal Analysis. New York: John Wiley and Sons, pp. 139–160.

Leung F (1981) Mills and Milling in Upper Canada. Ontario Government Publications, History and Archives 53.

Lovejoy CO, Meindl RS, Pryzbeck TR, and Mensforth RP (1985) Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death. Am. J. Phys. Anthropol. *68:*15–28.

Lukacs JR (1995) The 'caries correction factor': A new method of calibrating dental caries rates to compensate for antemortem loss of teeth. Int. J. Osteoarch. *5:*151–156.

Mandel ID (1993) Dental caries: Another extinct disease? In WH Bowen and LA Tabak (eds.): Cariology for the Nineties. Rochester: University of Rochester Press, pp. 1–10.

Mattick BE (1992) The history of toothbrushes and their nature as archaeological artifacts. Ms. on file, Oral-B Company, Toronto, Ontario.

Menaker L (1980) Biological Basis of Dental Caries, An Oral Biology Textbook. New York: Harper and Row.
Mintz SW (1985) Sweetness and Power: The Place of Sugar in Modern History. New York: Viking.
Moodie S (1853) Life in the Clearings versus the Bush. London: Richard Bentley (unabridged version, Toronto: McClelland and Stewart, 1989).
Moore WJ (1993) Dental caries in Britain. In C Geissler and DJ Oddy (ed.): Food, Diet and Economic Change Past and Present. Leicester: Leicester University Press, pp. 50–61.
Moore WJ, and Corbett ME (1971) The distribution of dental caries in ancient British populations 1. Anglo-Saxon period. Caries Res. *5:*151–168.
Moore WJ, and Corbett ME (1975) Distribution of dental caries in ancient British populations. III. The 17th century. Caries Res. *9:*163–175.
Newbrun E (1982) Sugar and dental caries: A review of human studies. Science *217:*418–423.
O'Sullivan EA, Williams SA, Wakefield RC, Cape JE, and Curson MEJ (1993) Prevalence and site characteristics of dental caries in primary molar teeth from prehistoric times to the 18th century in England. Caries Res. *27:*147–153.
Owsley DW, Orser CE Jr, Mann RW, Moore-Jansen PH, and Montgomery RL (1987) Demography and pathology of an urban slave population from New Orleans. Am. J. Phys. Anthropol. *74:*185–197.
Patterson DK (1984) A Diachronic Study of Dental Paleopathology and Attritional Status of Prehistoric Ontario Pre-Iroquois and Iroquois Populations. National Museum of Man Mercury Series: Archaeological Survey of Canada, Paper No. 122.
Rathbun T (1987) Health and disease at a South Carolina plantation: 1840–1870. Am. J. Phys. Anthropol. *74:*239–253.
Rogers TL (1991) Sex Determination and Age Estimation: Skeletal Evidence from St. Thomas' Cemetery Belleville, Ontario. Master's thesis, McMaster University, Hamilton, Ontario.
Rogers TL, and Saunders SR (1994) Accuracy of sex determination using morphological traits of the human pelvis. J. Forensic Sci. *39:*1047–1056.
Rudney JD, Katz RV, and Brand JW (1983) Interobserver reliability of methods for paleopathological diagnosis of dental caries. Am. J. Phys. Anthropol. *62:*243–248.
Rugg-Gunn AJ, and Edgar WM (1984) Sugar and dental caries: A review of the evidence. Community Dent. Health *I:*85–92.
Rushton MA (1965) The teeth of Anne Mowbray. Br. Dent. J. *119:*355–359.
Saunders SR, Fitzgerald C, Dudar C, and Rogers TL (1991) A test of several methods of skeletal age estimation using a documented archaeological sample. J. Can. Soc. Forensic. Sci. *25:*97–118.
Saunders SR, Herring DA, Sawchuk LA, and Boyce G (1995a) The nineteenth-century cemetery at St. Thomas' Anglican Church, Belleville: Skeletal remains, parish records, and censuses. In SR Saunders and DA Herring (eds.): Grave Reflections: Portraying The Past through Cemetery Studies. Toronto: Canadian Scholar's Press, pp 93–118.
Saunders SR, Herring DA, and Boyce G (1995b) Can skeletal samples accurately represent the living populations they come from? The St. Thomas' cemetery site, Belleville, Ontario. In AJ Grauer (ed.): Bodies of Evidence: Reconstructing History through Skeletal Analysis. New York, John Wiley and Sons, pp. 69–89.
Schwarcz HP, and Schoeninger MJ (1991) Stable isotope analyses in human nutritional ecology. Yrbk. Phys. Anthropol. *34:*283–322.
Sciulli PW, and Gramly RM (1989) Analysis of the Ft. Laurens, Ohio, skeletal sample. Am. J. Phys. Anthropol. *80:*11–24.
Shaw JH (1985) Diet and dental health. Am. J. Clin. Nutr. *41:*1117–1131.
Sledzik PS, and Moore-Jansen PH (1991) Dental disease in nineteenth century military skeletal samples. In MA Kelley and CS Larsen (eds.): Advances in Dental Anthropology. New York: Wiley-Liss, pp. 215–224.
Sutter RC (1995) Dental pathologies among inmates of the Monroe County Poorhouse. In AL Grauer (ed.): Bodies of Evidence: Reconstructing History through Skeletal Analysis. New York, John Wiley and Sons, pp. 185–196.
Thomas JFJ (1953) Industrial Water Resources of Canada—Upper St. Lawrence River—Central Great Lakes Drainage Basin in Canada. Canada. Department of Mines and Technical Surveys. Mines Branch, Industrial Minerals Division.
Tieszen LL, and Fagre T (1993) Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In JB Lambert and G Grupe (eds.): Prehistoric Human Bone: Archaeology at the Molecular Level. Berlin: Springer-Verlag, pp. 121–155.
Wells C (1968) Dental pathology from a Norwich, Norfolk burial ground. J. Hist. Med. Allied Sci. *23:*372–379.
Whittaker DK (1993) Oral health. In T Molleson, M Cox, AH Waldron and DK Whittaker (eds.): The Spitalfields Project, volume 2: The Anthropology, The Middling Sort, CBA Research Report 86, Council for British Archaeology, pp. 49–61.
Whittaker DK, Molleson T, Bennett RB, Edwards I AP, Jenkins PR, and Llewelyn JH (1981) The prevalence and distribution of dental caries in a Romano-British population. Arch. Oral. Biol. *26:*237–245.
Winchell F, Rose JC, and Moir RW (1995) Health and hard times: a case study from the middle to late nineteenth century in Eastern Texas. In AL Grauer (ed.): Bodies of Evidence: Reconstructing History through Skeletal Analysis. New York, John Wiley and Sons, pp. 161–172.
Winter GB (1990) Epidemiology of dental caries. Arch. Oral. Biol. *35:*1S–7S.